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Jatropa—The future fuel of India

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ABSTRACT

For India, there is a need to take a mission approach to explore the possibility of using straight/unmodified vegetable oils, their blends or biodiesels and their blends with mineral diesel as alternative fuel in order to achieve the twin objectives of reducing the emissions from the diesel engine and to increase the energy security of the country. Jatropa seems to the answer for India's energy woes. Millions of hectares of waste land is available in India and out of which about 33 million hectares of wasteland has been found to be suitable for Jatropa cultivation. Jatropa seems to be perfectly suited for India. However, all is not well for Jatropa in India. There are many social, technical and political issues to be sorted out before the dream of energy security through Jatropa cultivation could be realized. These problems and suggested solutions are dealt in detail in this paper. The suitability of Jatropa oil blends and Jatropa biodiesel blends in running of compression ignition has been evaluated and found that the performance of Jatropa oil and Jatropa biodiesel blends is very close to performance of diesel in the compression ignition engine. The break thermal efficiency, break specific energy consumption, CO, UBHC, NO_x emissions have been experimentally determined. A SWOT analysis of Jatropa with specific reference to Indian conditions has been carried out and found that Jatropa indeed is a plant which can make the Indian dream of self-sufficiency in energy—a reality.

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1. Introduction

India imports about 70% of its fuel requirement at a whopping cost of Rs. 80,000 crores a year. If 5% biodiesel fuel blends to the present diesel consumption in India would save about Rs. 4000 crores a year. The planning commission of India has launched ambitious bio-fuel project in 200 districts in India. It has recommended Jatropa (*Jatropa curcas*) and karanja (*Pongamia pinnata*) plant species as the most suitable species for biodiesel production in India [1]. *Jatropa curcas* belongs to the family of Euphorbiaceae. It is a small evergreen tree or softwood shrub 3–4 m in height. It is native to America but cultivated in tropical parts of the world. It is a monoecious plant. The current distribution of the world shows that its introduction has been most successful in the drier regions of the tropics with annual rainfall of 300–1000 mm [2–4]. It occurs mainly at lower altitudes (0–500 m) in areas with average annual temperatures well above 20 °C but can grow at higher altitudes and tolerates slight frost [5]. Each inflorescence yields a bunch of 10 or more ovoid fruits. Seeds normally mature 2–4 months after fertilization. Jatropha can be grown on very poor soils like sandy, saline, stony or even in the crevices of rocks [4]. It prefers alkaline soils. Jatropha can even stand droughts to some extent. Jatropha seeds contain 35–40% oil of seed weight and 50–60% of the kernel [6]. The uses of are various parts of Jatropa plant are well known to Indian rural population for ages. The latex of Jatropa has anti-cancerous properties, roots act as an antidote for snakebite, oilcake is used as manure, and leaves are a food for Tasser silk moths [7]. Forestation and re-forestation of degraded wastelands with Jatropa can convert unproductive lands into productive national assets. Jatropa is seen by many to be the perfect biodiesel crop for India.

In spite of Jatropa being so suitable to Indian conditions, the plant utilities being so very widely known for ages in this country, the national biodiesel mission working towards achieving its growth and spreading in various parts of the country, availability of large waste land areas suitable for its cultivation, etc., India has really not registered phenomenal growth in Jatropa cultivation and further production of Jatropa oil and its biodiesel. The current situation with regards to various problems faced by Indian farmers in Jatropa cultivation, strategies to be adopted to achieve targeted growth, and the policies required for its phenomenal growth in India are dealt in detail in this paper.

Jatropa oil, Jatropa biodiesel and their blends' performance on a twin cylinder 4-stroke water cooled engine with eddy current dynamometer has been evaluated and found that the break thermal efficiency, brake horse power, brake specific consumption are comparable to the fossil diesel performance. The Jatropa oil blends showed lower NO_x emissions when compared to the biodiesel blends.

2. Jatropa cultivation in India

The production of oil from Jatropa seeds begins with cultivation of Jatropa trees. The yield from the trees in the form of oil seeds depends on various factors like the location of the plant, climatic conditions, quality of the soil, irrigation practices, crop density, weeding, use of fertilizers, genotype, use of pesticide, type of intercropping, plantation establishment practices and plantation management practices including the production and use of all machines, and infrastructure needed for those inputs. Jatropa high ecological adaptability [5] allows it to grow in a wide range of conditions. As a succulent that sheds its leaves during the dry season, Jatropa is well adapted to semi-arid conditions, although more humid environmental conditions are shown to result in better crop performance. Jatropa plants have low nutritional requirements but are sensitive to pH of the soil. Acidic soil cultivation requires additional nutrients like calcium and magnesium [8].

Table 1
The category-wise waste land suitable for Jatropa cultivation.

		Category of wasteland suitable for Jatropha cultivation	Area (in million ha)
A		Non-forest cultivable wastelands	
	i	Gullied/ravinous-shallow (mainly community, Govt.)	1.03
	ii	Land with scrub (government/panchayats)	15.05
	iii	Land without scrub (mainly community, government)	3.74
	iv	Saline/alkaline-slight (mainly private)	0.41
	v	Shifting cultivation – abandoned (community)	1.22
B		Degraded forest land	
		Degraded forest – scrub	10.84
		Total	32.29

Jatropa crops have been recommended for cultivation in the wasteland [9,10] so that the cultivated lands may not be diverted for Jatropa crop. Wasteland is described as "degraded land which can be brought under vegetative cover with reasonable effort and which is currently underutilized and/or land which is deteriorating for lack of appropriate water and soil management or on account of natural causes." Wastelands can result from inherent or imposed disabilities such as location, environment, chemical and physical properties of the soil or financial or management constraints. Of the several categories of cultivable wastelands in India as given in Table 1, only 5 categories have been considered suitable for Jatropa cultivation covering an area of 21.45 million hectares (m ha). Similarly, the degraded notified forest area excluding arable land inside the notified forests covering 10.84 m ha is considered suitable for Jatropa cultivation [11]. The total wastelands area that is suitable for Jatropa cultivation, therefore, works out to 32.29 m ha.

32.29 m ha of land spread out in 23 states and Union Territories of India, which have been identified as potential areas for Jatropa plantation, is based on climatic conditions and potentiality for plantations. Jatropa has a high adaptability for thriving under a wide range of physiographic and climatic conditions. Extensive research work is being carried out for over a decade under the aegis of the National Oil Seeds and Vegetable Oils Development Board, Ministry of Agriculture, Government of India and on the basis of a wide consultation process involving a cross section of the society comprising Automobile manufacturers, Botanists, Agronomists, Foresters, Petroleum Technologists, farmers, NGOs, etc., but still India has really not taken off in a big way in Jatropa oil production. There are several issues which have caused this mismatch between what has been predicted and what really has been achieved [12]. There seems to be too many issues still

to be sorted in India before Jatropa cultivation could become profitable.

2.1. Economies of scale

The first and the foremost of the issues is economies of scale. Many experiences have shown that Jatropa as a biofuel source to be commercially profitable necessarily needs large-scale plantations. Several models can be put to practice to achieve this: viz. contract farming, leasing of forest lands or large scale land purchases to achieve large scale plantations, etc. However, farmers in India are experiencing contradictory laws to implement any of the above suggested methodologies to achieve economy of scale. Contract farming has great hurdles in India with respect to the financing from the banks [12]. Leasing of forests has a peculiar problem where in the leased person or organization has no right to harvest as the crop is from forests. Purchasing of huge tracts of land holdings is not allowed to protect the interest of the poor. Thus, in spite of having millions of hectares of waste land India is unable march forward in utilizing these natural resources in the cultivation of Jatropa on large scale. Some possible solutions to the standoff could be providing special permissions or rules for Jatropa plantations similar to those provided for coffee/tea plantations. The government has to come out with specific policies for Jatropa cultivation. A single organization is to established covering various ministries which could take decisions on project approval for a particular area based on extensive research, financing, seed collection, oil extraction, biodiesel production, marketing, management of byproducts and finally dealing at international level for carbon credit trading, etc. However, the Government of India seems to be moving in the opposite direction. Economic times of India news report suggests a group of ministers in India quietly dropped a national biodiesel mission before it even got started. The national mission would have invested Rs. 14,000 crore to plant four million hectares of biodiesel crops including Jatropa and sweet Sorghum [13].

2.2. Intercropping

The profitability of Jatropa cultivation in India as a mono crop itself is in question judging by experiences of farmers in various states of the country. From different experiences in this country it is clear that cultivation of Jatropa singularly is not a very attractive proposition and the suggested solution is intercropping [14]. According to the topography, soil profile and prevailing agro climatic conditions in an area, Jatropa can be combined with other suitable species comprising agricultural, horticultural, herbs, pastoral and/or silvicultural components to result in an ecologically viable, economically profitable and socially acceptable agro forestry system. By evolving, promoting and adopting Jatropha based intercropping systems it is possible to improve the socioeconomic conditions in rural areas and to transform the National energy scenario and the ecological landscape. Intercrops like red and green peppers, tomatoes, karela (*Momordica charantia*), water melons, etc., would provide additional income to the farmers. This could become very handy especially during the initial years of Jatropa cultivation as the full yield of Jatropa can be realized after about five years. SRIPHL [15] has tried out number models of intercropping successfully which include Eucalyptus, *Moringa olefira*, medicinal plants like *Asparagus racemosus* (Shatawar) and *Commiphora mukul* (Gugul).

Socio economic advantages of multiple cropping systems with Jatropa as the main crop:

- Sole dependence on Jatropa yield for income can be reduced as the full yield from Jatropa can be obtained after about 2–5 years.
- Payback time of intercrops is less which would result in an income to the farmer in the initial periods of Jatropa cultivation.
- Labour employment and their income can be year round as same labour can be utilized for both crops.
- Jatropa can act as insurance to farmers for his long term income and intercrop can cater to his immediate income requirements.
- The farmer of little economic resources can produce a large variety of useful products.

2.3. Policies of government

There seems to a be clear policy deficiency from the experiences of various farmers in India [14] to attain self-sufficiency on the energy sector front India needs to have policies for development of a strong biofuels industry. Sustained commitment from government in terms of budget allocation, intersectoral coordination, and policies to provide an appropriate set of incentives for producers, processors and consumers to be developed is the need of the hour. Policies of national welfare and energy security could be linked to the biofuels programs. For example national employment guarantee scheme in rural areas could be linked to the Jatropa cultivation.

Government also needs to be prepared for constant review and adaptation, providing a flexible policy environment.

The following are some of the policy initiatives could make the large-scale Jatropa cultivation and usage closer to reality:

- A central nodal agency needs to be created especially for energy security through biofuel programs which can deal with the specific issues of biofuels like land rights, forest cultivation, utilization of waste lands, financing of biofuel crops, zone specific research and the cultivation technologies to be adopted, etc., to remove mismatch of feedstock to prevailing biophysical conditions.
- Promote access to biofuel technologies including cutting-edge technologies. This could involve, for example, import tariff reductions to biofuel technological goods and training in the use, transfer and adaptation of biofuel technologies.
- Promote access to finance/credit. This may include provision of soft-loans, guarantees, cooperation with international financing institutes for large scale financing requirements at soft credit terms.
- Create market infrastructure, testing of the technology and demonstrate production potential, supporting setting up of district level seed collection and oil production centers.
- A complete life cycle plan which includes region specific research, educating the farmer, cultivation practices, actual field level cultivation, seed collection, oil production and its local utilization to be developed involving all the stake holders like researchers, farmers, financing institutions, engine manufacturers, and finally end users. Policies, for ensuring only quality planting materials and other inputs are available and are used, are needed.

2.4. Availability of quality planting materials and other inputs

Availability of superior planting materials, production machinery and matching agro production techniques for harnessing the crop's full productivity is very important. However, these are severely lacking at present in India. There are big claims but the truth is far from these claims. No valid and reproducible information is available on Jatropa culture and management in single or inter cropping situations. Whatever information is currently available either from governmental organizations or from others seems to be based on either experiences from similar crops/species rather than experimentations with a research objective. Jatropha is usually grown from seeds but it can also be propagated by branch

cuttings, i.e., both vegetative and generative forms of propagation. The quality of Jatropa seedlings depends on two factors, i.e., (i) genetic makeup of the parent stock and (ii) physical growth of seedling. The genetic traits depend on the parental population. Lot of variation exists in natural population of Jatropha with respect to seed yield (0.2–2 kg/tree) and oil content (30–48%) since it is widely distributed in different climatic conditions in the country. Therefore, selection of seed sources is important and primary need of developing high quality planting material of Jatropa. Thus, the quality of seedlings would affect the ultimate economics of the Jatropa cultivation [16].

2.5. Farmer level knowledge dissipation

Misinformation and hype created about Jatropa's adaptability and yield in itself seems to be acting against the Jatropa cultivation in India. The spree of ambitious plans unleashed by various State as well as Central Governments for its large scale promotion and development and the exciting business opportunities they opened to agri-entrepreneurs, the result—mushrooming of a plethora of biodiesel processors, scientists' and farmer turned seeds men, self-appointed consultants with promise of incredible yields and income lead to country-wide euphoria in the crop right from small to large farmers irrespective of their specific agro ecological and crop growing situations. A number of over enthusiastic farmers even took up Jatropha in their agricultural fields often under high input conditions and in preference to their traditional crops. Ranga Rao [12] in his work has found the realty too harsh from the hype that has been created around the Jatropa plant. He observed that quite contrary to the widely publicized claims, none of the plantations of 3 years or more video graphed by him exhibited either the kind of productivity levels promised or the fruiting potentials (i.e., bunch number and size, etc.) expected of plants capable of yielding one kg/year under the system of block plantations. Far from the reported bumper yields, extension of Jatropha into situations which are totally alien to it namely fertile soils with favorable moisture and input regime only led to very luxuriant and unproductive vegetative growth. He also observed that the crop turned out to be as vulnerable as any other crop to insect pests and diseases (e.g., Collar rot, bark eater, defoliators, powdery mildew, leaf spots, termites, leaf minor, etc.) once it is removed from its original habitat and put under high density and intensive cropping system. He also observed that the average yields from the currently available planting materials in dry-lands are unlikely to exceed 400 kg/ac/year (or = 1 t/ha/year). The current situation has actually resulted due to the conspicuous the absence of authentic data, as not much research work with respect to Indian conditions prevailing in various states of the country is available.

Euphoria is actually based on international reports of 5–10 t/ha/year based on extrapolation of yields from per meter length of hedge grows in countries like Cape Verde and Nicaragua. Another popular belief is that Jatropa is pest resilient but research has shown that it is also prone to pests inflorescence and capsule-borer *Pempelia morosalis*, and the scutellarid bug Scutellera are the major problems of Jatropa monocultures observed in India [17]. *Pachycoris klugii* (Scutelleridae) and *Leptoglossus zonatus* (Coreidae) are the pests identified in Nicaragua [18]. From Rao's observations [12] it becomes very clear that in spite of versatility of Jatropa owing to its short gestation period, excellent re-generation capability, long productive life, adaptability to varying climates, ability to grow in arid and tropical climates, etc., any plans for large scale commercialization are unlikely to succeed without back up of appropriate and relevant region and situation specific research, ground level information to farmers and quality planting materials and agro production techniques.

2.6. Uses of Jatropa plant

The various parts of the plant are very useful and are well known for ages in India. However, the tree has gained importance over the years as the non edible oil produced from its seeds has physio-chemical properties [43] similar to the petroleum diesel and can be utilized in a diesel engine.

The oil is used for ages in India for lighting the lamps and it burns with smoke free flame. It is being extensively used in soap making industry. Jatropa oil cake can be used as manure as it contains both nitrogen and phosphorous. Jatropa leaves are used as food for the tusser silkworm. The latex of Jatropa is believed to contain anti-cancerous properties. The roots are believed to work as an antidote for snake poison. Thus Jatropa can be termed as a wonder plant like coconut of Indian households where every part of it is useful. Being rich in nitrogen, the seed cake is an excellent source of plant nutrients. This residual de-oiled cake contains 38% protein, 3.2–44% N, 1.4–2.09% P and 1.2–1.6% K. With the combination of oil production and erosion control and the ability to grow in marginal areas with poor soil and low rainfall, this species has great potential in rural development as a source of house hold income and at the same time creating environmental benefits [19].

Thus to achieve the objectives of energy self-sufficiency through Jatropa in India a lot of research seems to be inevitable in Jatropa cultivation with specific goals. Biotechnology developments may also be roped in to develop better oil yielding Jatropa plantations specific to the site and climatic conditions. The farmers are to be educated regarding the actual region specific processes to be adopted in the Jatropa cultivation. Extensive work and field trials in different zones of the country are required to identify and establish the intercrops possible to make Jatropa a viable alternative for the farmer. Instead of limiting Jatropa cultivation to farmers it has to be taken up as a national objective to grow Jatropa say at homes, schools, colleges, parks and other possible areas where land is available. There should be local seed collection and oil production facilities at district level to utilize this national revolution. Every Indian should take this up as an objective to grow at least a Jatropa tree to make India self-reliant in energy

3. Jatropa oil production and use

Jatropa oil [JO] from seeds can be obtained by Mechanical expellers. Normally the seeds are dried to about 105° before they are expelled in mechanical expellers [20] to remove the humidity and mechanical expellers can be engine driven screw type of expellers or manual ram type. Many researchers have identified that screw type expellers can extract about 75–80% oil from the seeds leaving out the seeds or kernel cake which is an important byproduct of the Jatropa oil extraction [21]. In the chemical extraction process the grounded and crushed kernels are used as feed and the output depends upon various factors like the temperature of the reaction, pH value, the amount of time taken for the reaction. The n-hexane method which takes longer time for the reaction is the most common method of oil extraction by the chemical process. However, Adriaans [22] does not recommend the n-hexane process due to environmental impacts of the process. Using aqueous enzymatic oil extractions greatly reduces these problems [22].

The Jatropa oil characteristics especially the quality of oil depends on the interaction of environment and genetics. As for the seed size, seed weight and oil content, oil quality [23] it is believed that the environmental conditions have a larger impact than the genetics. More research is necessary with respect to Indian climatic, soil, water availability, etc. The Jatropa oil basically consists of oleic acid (C18:1) and linoleic acid (C18:2), 37–63% and 19–41% (%, w/w),

respectively. It is also believed that the maturity age effects the fatty acid composition [24].

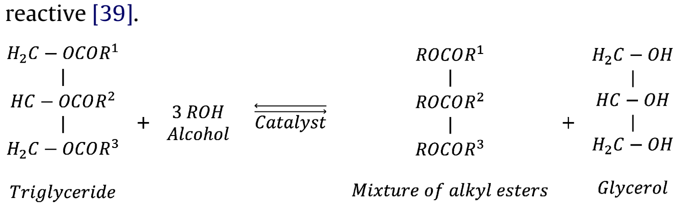
Vegetable oils have been found to be a potential alternative to diesel. They have properties comparable to diesel and can be used to run a compression ignition engine without or with minor modifications [25,26]. Jatropa oil is also characterized by physico-chemical properties similar to petroleum diesel for its usage in a diesel engine except a very high viscosity. Higher viscosity of the vegetable oil causes poor fuel atomization, incomplete combustion and carbon deposition on the injector and valve seats. This results in serious engine fouling. It has been reported that when direct injection engines are run with neat vegetable oil as fuel, injectors get choked up after few hours and lead to poor fuel atomization, less efficient combustion and dilution of lubricating oil by partially burnt vegetable oil [27].

Tests with a low heat rejection diesel (LHR) engine showed that the use of pure Jatropa oil results in a higher brake specific energy consumption (BSEC), lower brake thermal efficiency (BTE), higher exhaust gas temperature (EGT) and lower NO_x emissions in comparison with fossil diesel [28] Preheating and increasing the injection pressure decreased BSEC, increased BTE, increased EGT and increased NO_x emissions only marginally. Kumar et al. [29] compared the use of Jatropa oil and fossil diesel in a single cylinder 4-stroke water-cooled diesel engine and concluded that the soot (hydrocarbon) emission is higher with Jatropa oil as compared to fossil diesel. At maximum output an increase from 100 ppm, for fossil diesel, to 130 ppm, for Jatropa oil, was measured and similar trends were observed in the case of CO emissions. Smoke level was higher with JCL oil (4.4 BSU) compared to fossil diesel (3.8 BSU) as well. Furthermore, they observed an increase in ignition delay and combustion duration with JCL oil in comparison to fossil diesel.

The main disadvantages of vegetable oils as diesel fuel are higher viscosity, lower volatility, and the reactivity of unsaturated hydrocarbon chains. The problems met in long-term engine tests, according to results obtained by earlier researchers, may be classified as follows: coking on injectors, valve seats [30,31] more carbon deposits, oil ring sticking, and thickening and gelling of the engine lubricant oil [32–35]. Vegetable oils can be used as fuels for diesel engines these oils are extremely viscous, with viscosities ranging from 10 to 17 times greater than diesel fuel with 10–20 carbon number hydrocarbons [35–37]. Different methods have been considered to reduce the viscosity of vegetable oils such as heating, dilution, micro emulsification, pyrolysis, catalytic cracking and transesterification.

3.1. Jatropa biodiesel [JB] production and characteristics and use

The name "biodiesel" has been given to transesterified vegetable oil to describe its use as a diesel fuel [38]. Transesterification is the process of exchanging the alkoxy group of an ester compound by another alcohol catalyzed by the addition of a base and acid. Bases can catalyze the reaction by removing a proton from the alcohol, thus making it more reactive. Acids can catalyze the reaction by donating a proton to the carbonyl group, thus making it more reactive [39].



Vegetable oils can be transesterified by heating them with a large quantity of anhydrous methanol and a catalyst. Various studies have been conducted on the transeterification methods using [40] acids [41] and enzymes [42] as catalysts.

Table 2
The physicochemical properties of Jatropa oil and its biodiesel [43].

Sl. no.	Property	Jatropa oil	Jatropa biodiesel
1	Density	918.8	879.4
2	Flash point (°C)	186	135
3	Sp. gravity (60/60 F)	0.9193	
4	Ash content (wt%)	0.07	0.013
5	RI at 40 °C	1.4691	
6	Sulphur (ppm%)	21.5	
7	Kinematic viscosity 40 °C (cSt)	35.47	4.34
8	Molecular weight	887.7	320
9	Pour point	−6	+3
10	Carbon residue (%)	0.3	
11	Cu strip corrosion	1	1
12	Acid value (mg/gKOH)	5.31	0.38
13	Iodine value/100 g	114.6	
14	Cetane number	38.1	58.4

The viscosity values of vegetable oil methyl esters decrease sharply after transesterification. Compared to diesel fuel, the vegetable oil methyl esters are slightly viscous. The flash point values of vegetable oil methyl esters are significantly lower than those of vegetable oils. These parameters are all specified through the biodiesel standard, ASTM D 6751.

Kaul et al. [43] have characterized physicochemical characteristics of various straight vegetable oils and their biodiesels including Jatropa of Indian origin. The same have been tabulated in Table 2.

Sahoo and Das [44] in their work Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine have shown that the transesterification process improved the fuel properties of the oil with respect to density, calorific value, viscosity, flash point, cloud point and pour point. The comparison of these properties with diesel showed that the methyl esters of Jatropha, Karanja and Polanga oil have relatively closer fuel property values to that of diesel. They have observed that the typical combustion characteristics of Jatropha, Karanja and Polanga biodiesels are in the close range of the operational requirements of the engine. They also observed shorter ignition delays with pure Jatropa 1 biodiesel and higher peak pressures when compared to petroleum diesel. Ramesh and Sampathrajan in their investigations on performance and emission characteristics of diesel engine with jatropha biodiesel and its blends [45] identified that the jatropha biodiesel performed similar to that of diesel fuel in diesel engine as far as power output at different loads. However, they found that the specific fuel consumption increased from 3% to 14% for varying percentage of Jatropa biodiesel blends from 20% to 100%. They also observed that the brake thermal efficiency was slightly higher with biodiesel blends than the diesel fuel at different loads, the reduction in carbon moNO_xide emission was lesser by 14–16% with an increase in NO_x emissions by 15–19%.

Lee et al. [46] investigated the combustion and emission characteristics of biodiesel–diesel blended fuels. They reported that as the blending ratio of the biodiesel fuel is increased, HC and CO emissions decreased, while NO_x emission increased. This behavior is attributed to the increase of the combustion temperature promoted by the oxygen in the biodiesel fuel. Hong et al. [47] compared the spray characteristics of diesel and biodiesel fuel using high-pressure fuel injection. They found that the spray tip penetration of biodiesel fuel is greater than that of diesel, but the spray cone angle is less than that of diesel. They also reported that the decrease in the spray angle is related to the increased spray tip penetration. Besides, Kegl et al. [48,40] and Schonborn et al. [49] investigated the optimal fuel injection system and the effect of the molecular structure on the NOx and PM (particulate matter) formation of biodiesel fuel, respectively.

Most of the cited literature is of international researchers and there is need for more research in India on various kinds of engines both for short term and long-term

Table 3
Physical and chemical properties of Jatropa oil blends.

Fuel	Density at 15 °C (g/c.c)	Kinematic viscosity at 40 °C	Calorific value (kJ/kg)
Joil 100%	0.92	45.75	39.15
Joil 20%	0.881	4.3	43.10
Joil 30%	0.887	5.8	42.75
Joil 40%	0.894	7.51	42.15
Joil 60%	0.907	17.01	41.30
Joil 80%	0.915	26.58	39.90
Diesel	0.840	2.75	44.60

engine usage. With this in view the present experiment is carried.

4. The present experiment

After understanding the various problems and solutions associated with large scale Jatropa cultivation, published literature was combed for Jatropa oil and its biodiesel usage either in pure form or blended with petroleum diesel usage in compression ignition engine. From the literature it is observed that not much published Indian research work was found. Definitely more research work in this direction is warranted. With this in mind Jatropa oil, Jatropa biodiesel both in pure form and blended with diesel were tested in a twin cylinder 4-S, 14 BHP water cooled engine.

The biodiesel for the experiment was prepared on a laboratory scale

4.1. Preparation of Jatropa biodiesel

Transesterification of Jatropa oil was carriedout by a base catalyst. In transesterification process the oil was taken in a three necked round bottom flask and heated with stirring for 10 min continuously at a temperature 100 °C to remove excess moisture. The weight ratio of oil: methanol was taken as 1:3. Sodium methoxide as base catalyst (1.5% of oil and methanol) was mixed well with methanol. The base–methanol mixture was added slowly with oil in the round bottom flask that was fitted with thermometer and condenser. The reaction mixture was stirred vigorously with heating for 2 h at 69 °C. Then the mixture was cooled by ice water. Two layers formed, the upper layer was product layer and the lower layer was glycerol layer. The upper layer was taken in a separating flask and washed three times by distilled water to remove catalyst and methanol. The washed oil was stirred with anhydrous sodium sulphate and kept for 3 h at room temperature for dehydration. Jatropa biodiesel thus produced at a laboratory scale was tested for various physical and chemical properties.

The properties of Jatropa oil and its blends, and Jatropa biodiesel (Jatropa methyl esters) and its blends are tabulated in Tables 3 and 4.

Table 4
Physical and chemical properties of Jatropa biodiesel blends.

Fuel	Density at 15 °C (g/c.c)	Kinematic viscosity at 40 °C (cSt)	Calorific value (kJ/kg)
JB100%	0.880	4.35	39.4
JB 20%	0.860	2.95	43.27
JB30%	0.863	3.03	42.60
JB 40%	0.865	3.23	42.03
JB 60%	0.870	3.52	41.16
JB 80%	0.876	3.96	40.23
Diesel	0.840	2.75	44.60

Table 5
Engine specifications.

Engine make	Kirloskar
No. of cyliders	Two
Power	14 BHP@1500 rpm
Bore and stroke	87.5 mm × 110 mm
Ac generator capacity	10 kVA 3φ 440 V 50 Hz
Compression ratio	17.5:1

4.2. Performance evaluation of Jatropa oil and Jatropa biodiesel

Jatropa oil, Jatropa biodiesel and blends of both in various volumetric proportions (20%, 30%, etc.) have been tested for both engine performance and emissions in twin cylinder compression ignition engine. These mixtures were prepared and utilized immediately on preparation.

4.2.1. Experimental set up

Twin cylinder 4-S 14 BHP water cooled engine with electrical dynamometer was used for the present work. The Jatropa oil as well as Jatropa biodiesel blends with diesel on volumetric basis were prepared and tested in the engine.

Short-term engine performance tests were carried out on the diesel engine (Table 5) with neat diesel oil, JO 20, JO 30, JO 40, JO 60, JO 80, JO 100 and similar blends of Jatropa biodiesel. The objective of such a study was to compare the suitability of these fuels for engine applications. Engine systems quipped with experimental technologies to evaluate performance parameters such as brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), brake mean effective pressure (BMEP), brake thermal efficiency (BTE), and volumetric efficiency.

To evaluate the performance parameters, engine shaft speed, generator output, fuel consumption rate, airflow rate, temperature of engine cooling water, and engine exhaust gases were measured. The performance parameters were calculated from the fundamental relations between these measurements while varying the load on the engine from 0% to 100% in steps of 20%.

Engine emissions like carbon monoxide, carbon dioxide, nitrogen oxides, oxygen, smoke, and unburned hydrocarbon were measured with an AVL five gas analyzer and a smoke-meter (AVL 437). The sensor of the analyzer was exposed to the engine exhaust and the observations were recorded. The measured emissions were analyzed and interpreted graphically as shown in Figs. 5–10.

5. Results and discussions

Jatropa oil blends and Jatropa biodiesel blends were used separately in the compression ignition engine without any engine modifications. The performance and emissions of the engine with diesel, blends of Jatropa biodiesel, and blends of Jatropa oil are presented and discussed below.

Performance analysis of Jatropa biodiesel and Jatropa oil blends significant engine performance parameters, such as brake specific energy consumption (BSEC) and brake thermal efficiency (BTE) for Neat Jatropa biodiesel (JB) and its blends with diesel (JB20%, JB30%, JB40% JB60% JB80%) were calculated. Similarly, the same type of blends was also analyzed for Jatropa oil (JO) blends. These results are analyzed and represented graphically in the following figures.

5.1. Brake thermal efficiency (BTE)

The trends of BTE for J30 improved slightly as compared to neat petroleum diesel which can be seen from Fig. 1. This could be possibly due to higher lubricity and better combustion effects as the fuel contains more oxygen. The BTE for J30 was higher at full load

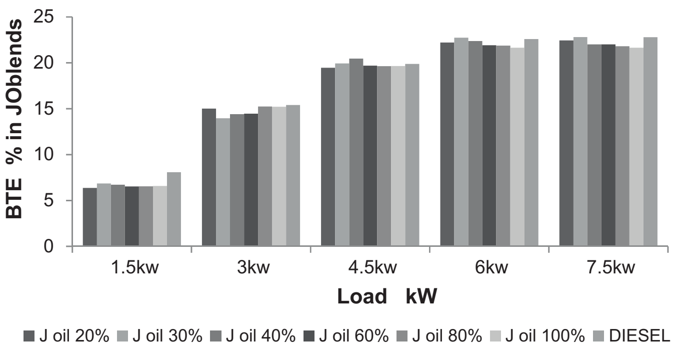


Fig. 1. Plot of BTE vs. load for JO blends.

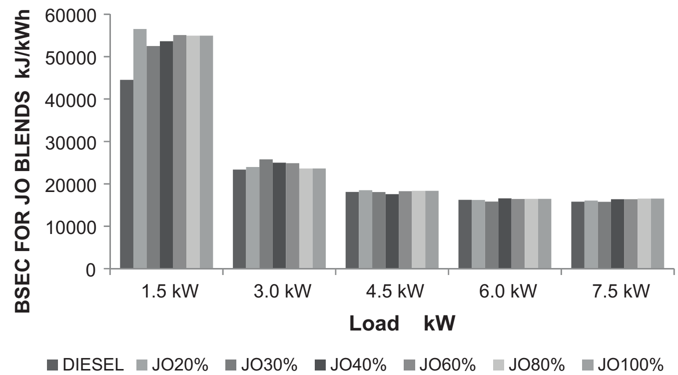


Fig. 3. Plot of BSEC vs. load for JO blends.

in comparison to petroleum diesel. However, for all other blends BTE was lower than petroleum diesel.

The trends of BTE for lower percentage JB blends at lower loads perform better as can been seen in Fig. 2. However, the higher percentage blends at lower loads have poorer performance. This could possibly because of two reasons. The JB blends are characterized by higher viscosity and availability of more oxygen for better combustion. Higher viscosity of the fuel is probably contributing to the better lubricity and higher oxygen content contributing to the better combustion process. Biodiesels have good lubricating properties and are about 66% better in lubrication than the petroleum diesel; even a 1% biodiesel would increase the lubricity by 30% [50]. A combination of these two factors probably make the lower blends perform better than higher percentage blends. However, the higher percentage blends tends to have lower BTE at all loads. This could possibly be due to the factor of higher viscosity of the fuel and improper spray and improper combustion overtaking the lubricity benefits gained. JB20 blend seems to perform better than all other blends at all loads JB 100 performance being the lowest. As expected diesel has higher BTE than all JO blends.

5.2. *Brake specific energy consumption (BSEC)*

BSEC of JO blends and JB blends are plotted in Figs. 3 and 4. The BSEC of both JB blends and JO blends is slightly higher when compared to petroleum diesel. Though BTE for the JO30 is better than the petroleum diesel but its BSEC is higher than petroleum diesel as can be seen from the Figs. 8 and 9. The cause for the increase in the BSEC may be attributed to lower heating value, higher density, lower volatility of Jatropa oil and its biodiesel. Improper combustion due to higher viscosity, smaller fuel spray angles and greater fuel penetration adversely affect the engine performance [51]. These results are in agreement with the published work with poon oil and karanja oil [44,52].

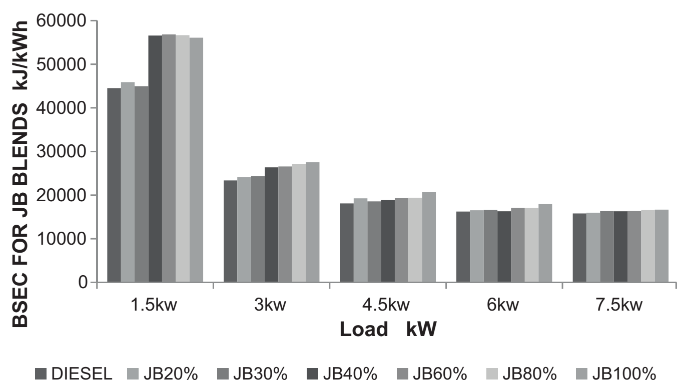


Fig. 4. Plot of BSEC vs. load for JB blends.

5.3. *Carbon monoxide emission*

Carbon monoxide (CO) emission of Jatropa oil blends in lower percentages J10, J20, J30 are lower than the higher percentage blends as can been seen in Fig. 5. Lower CO emission in the lower JO blends probably due to higher oxygen availability in the fuel. However, the results with higher blends are different with higher CO emissions. Higher viscosity, improper spray pattern with higher JO percentage resulting in incomplete combustion may have increased the CO emissions.

However, different trends were observed with JB blends as can be observed from Fig. 6. With increasing percentage of blends CO emission reduced when compared to petroleum diesel. This could be attributed to lower viscosity of JB blends than the JO blends, higher oxygen availability, resulting in higher ignition temperature. These results are in agreement

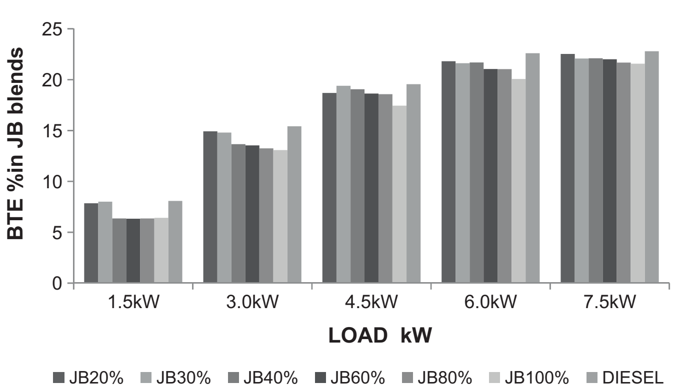


Fig. 2. Plot of BTE vs. load for JB blends.

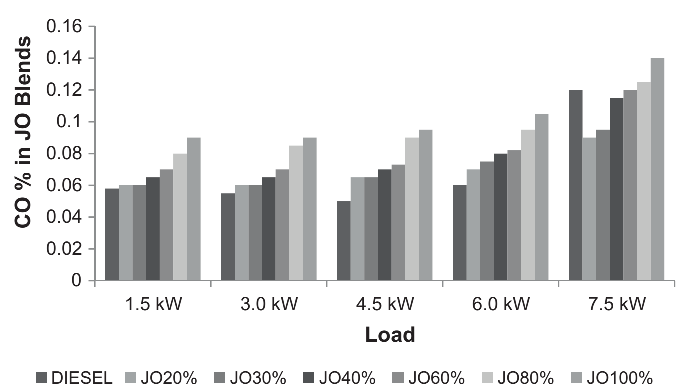


Fig. 5. Plot of CO vs. load for JO blends.

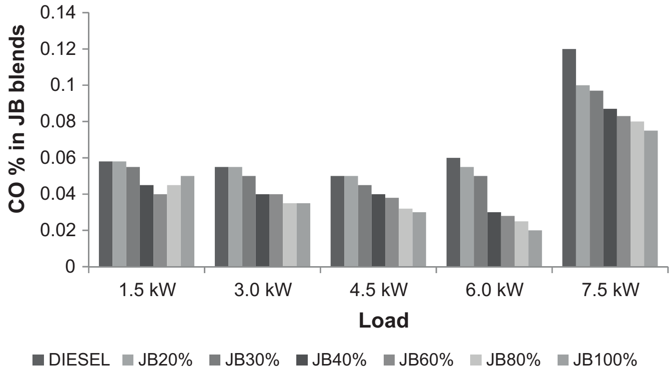


Fig. 6. Plot of CO vs. load for JB blends.

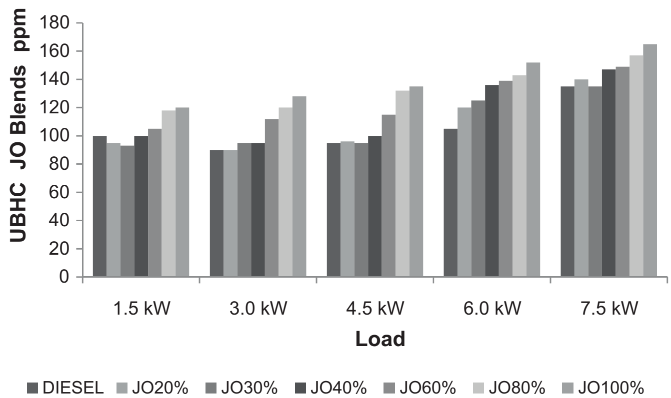


Fig. 7. Plot of UBHC vs. load for JO blends.

with the published work with other straight vegetable oil blends.

5.4. Unburnt hydrocarbon emissions (HC) emissions

UBHC for both JO and JB blends are plotted in Figs. 7 and 8, respectively. UBHC of JO blends are higher at higher loads when compared to petroleum diesel. Increasing JO in the blend increased the HC emission which can be attributed to higher viscosity of the blend and the poorer spray pattern. However, JB blends vary from this trend. HC emissions showed decreasing trend with increasing percentage of JB in the blends. The higher the percentage of JME in the blend the lesser is the HC emission indicating better combustion due to higher availability of oxygen.

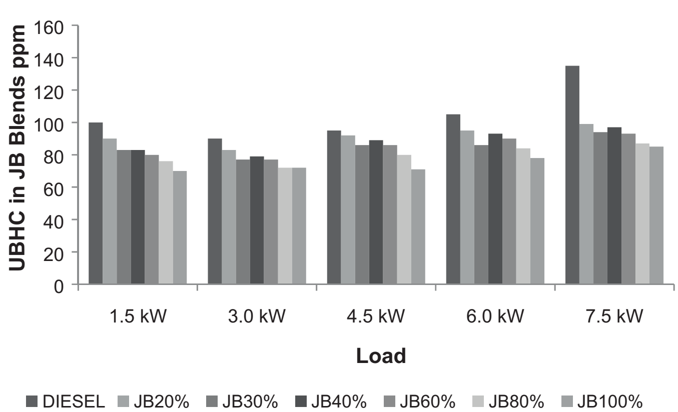


Fig. 8. Plot of UBHC vs. load for JB blends.

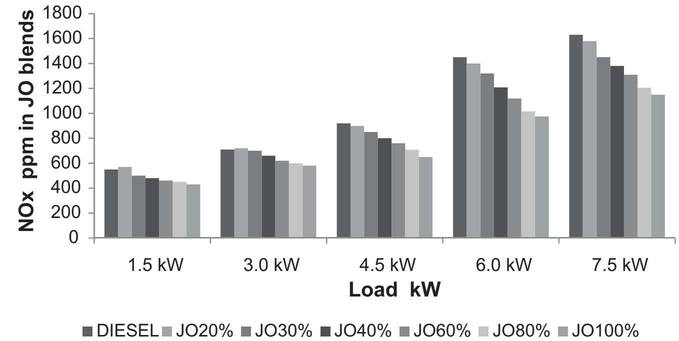


Fig. 9. Plot of NO_x vs. load for JO blends.

5.5. NO_x emissions

Trends of NO_x emissions in case of JO oil blends and JB are shown in Figs. 9 and 10.

NO_x emissions are of more important to the present engine designers, environmentalists and governments to comply with the international agreements for its reduction. The future of diesel engine is in fact under threat from this emission as it is approximately300 times more harmful than the CO_2 [53].

As engine load is increasing NO_x emissions are increasing prove that only thermal NO_x is dominating and prompt and fuel NO_x do not much role with JO oil blends combustion.

JO oil blends have the potential to reduce NO_x emissions as can be seen from the plot. In Fig. 9, the reduction obtained with JO blends is probably due to lower combustion chamber temperature with JO blends because of lower heating values of JO and its blends.

JB blends have totally different trends. The JB blends have lower NO_x levels than diesel but increased NO_x emissions than the JO blends. This could be well understood in the light of better combustion of JB blends than the JO oil blends resulting in higher combustion chamber temperatures and thus higher NO_x emissions. The diesel in pure form has highest NO_x emissions among the JO blends, JME blends and JO oil in pure form has the lowest NO_x emissions.

6. SWOT analysis for Jatropa as energy provider for India

A SWOT analysis has been carried out for Jatropa as energy provider and as future fuel of India and it has been found that Jatropa indeed can be the future fuel of India

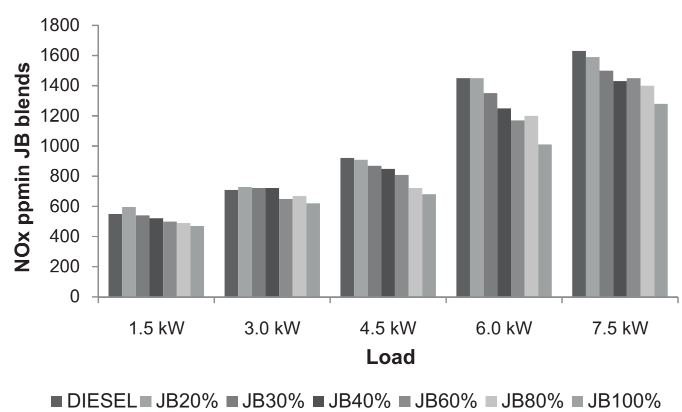


Fig. 10. Plot of NO_x vs. load for JB blends.

6.1. Strengths

- It is a non edible vegetable oil.
- It has high oil content when compared to other tree borne oil varieties.
- Jatropa is a hard and highly adaptable crop that can grow in marginal soils from an average annual rainfall of 250 mm. As such JCL is capable to reclaim wasteland.
- Jatropha can convert unproductive lands into productive national assets.
- It can start giving yields right from 2nd year and has a productive life of 50 years.
- All parts of this plant are very useful.
- Production of Jatropa oil and Jatropa biodiesel is well established in India.
- Jatropa biodiesel has physicochemical properties of petroleum diesel and can be used C.I. engines by blending with diesel.
- It is renewable source of energy.
- It can make India self-reliant in energy needs of transport sector instead of depending on imported fossil fuels.

6.2. Weaknesses

- No information on cultivation practices at the grass root level.
- Misinformation spread out on presumptions and extrapolated results of other countries.
- Lack of authenticated and published work with respect to cultivation practices specifically with respect to Indian conditions.
- Varying oil yields.
- Information on inputs required for higher oil yield not available.
- By products usage still not very popular.
- Extension of Jatropa into fertile soils with favorable moisture and input regime needs detailed research as some experiences have shown that it led to only very luxuriant and unproductive vegetative growth.
- Lack of good quality planting materials and machinery for cultivation.
- Crop is as vulnerable as any other crop to insect pests and diseases especially once it is removed from its original habitat and put under high density and intensive cropping system (e.g., Collar rot, bark eater, defoliators, powdery mildew, leaf spots, termites, leaf minor, etc.)
- Economic viability as a mono crop is under question.
- Economic viability depends on intercropping which needs case specific intensive research.

6.3. Opportunities

- Depleting fossil fuel reserves all over the world.
- India's profound dependence on imported fossil leading to energy insecurity.
- Large tracts of waste lands up to 32 million ha available which are suitable for cultivation of Jatropa.
- Carbon credits trading can make the crop economically viable in a mono cropping systems.
- The projected demand of biodiesel at 5% blending requires a 3.5 million metric tons of biodiesel and an acreage of 2.79 Mha and proportionately increases with increase in blending ratios.
- Availability of large farm labour.
- Opportunity of huge exports to developed countries where either non availability of land or cheap labour makes the Jatropa cultivation too expensive.
- Huge potential for employment generation resulting in economic economic growth of the rural poor.

6.4. Threats

- Large amount of misleading and improper information spread out among the farmers.
- Most of the information available is not based on actual research results butt rather extrapolated results or experiences from other countries.
- Appropriate and relevant region and situation specific planting materials and agro production techniques are lacking.
- Ground level facilities like availability of quality planting materials and machinery, seed collection centers, oil mills and byproduct management are lacking.
- As of today the actual biodiesel is costlier than the fossil fuel.
- Outdated and shortsighted policies of the government.

7. Conclusions

Jatropa indeed seems to be a wonder plant which can change the Indian energy scenario from dependence on oil producing countries to energy self-reliant country. The path, however, does not seem to be easy one. Urgent and sweeping policy change over is required. India has large tracts of wastelands and huge farm labour. This is a huge opportunity for India to seize. Educating the farmer is the most urgent need of the hour as wrong and improper information can lead to irreparable damage to an enormous opportunity knocking the doors of the nation.

Practical and visionary policy goals from the government are not only expected but are warranted at this juncture.

The performance tests of diesel engine carried show that the BTE, BSEC of both Jatropa oil blends and Jatropa bio diesel blends are comparable to petroleum diesel. There seems to be a gain in the emission side with Jatropa oil blends showing lower NO_x emissions and Jatropa biodiesel blends showing lower CO and UBHC emissions. There is a need for research to obtain the positive aspects of both Jatropa blends and Jatropa biodiesel blends in order to have sustainable biodiesel usage in the longer run. Probably suitable additives may do the wonder in the longer run.

Given the Indian climatic conditions in many parts of the country are similar to the required conditions for cultivation of Jatropa, the country being endowed with vast stretches of waste, barren and underutilized lands and the opportunities it offers for year round cultivation, availability of enormous farm labour, a huge market potential for the end product, the dream of making India energy self-reliant through Jatropa is certainly not an impossible task.

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